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NEW VERTICAL KILN PROCESS FOR CEMENT MANUFACTURE

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NEW VERTICAL KILN PROCESS FOR CEMENT MANUFACTURE

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1. In recent years, systematic studies in many parts of the world have been conducted with the objective of designing a kiln which would perform fully uniform sintering of cement clinker in a press-button controlled automated process. It has been known for many years that it is possible to automate high temperature processes fully only if they can be made independent of the need for visual observation. For a number of reasons, this cannot be achieved in rotary kilns and so the vertical kiln has been an object of intensive research. It promised to become possibly the first fully automatic sintering unit to be operated by remote control from a laboratory panel, without even a television set necessary to observe flow in the kiln or cooler. The research objective was to perfect accuracy of proportioning, and uniformity of raw materials and fuel sizing to such extent that eventually full atuomation of the sintering process might become feasible.

2. In 1947 introduction of the pan type nodulizer opened up such possibilities. The nodulizer enabled embedment of fuel particles completely in the raw meal thus opening the way to use of highly volatile fuels and bringing particle size of fuel and raw material into the same range.

3. The use of highly volatile fuels greatly improves uniformity of sintering by an exceptionally fast rate of heat transfer. This was learnt in large scale experimental work carried out during the last war to fire a modernized vertical kiln with heavy residual oil. Feed to this kiln was produced in a Krupp Excenter rolling press, producing ½ in by 1 in diameter cylinders, while the fuel oil was pressure-atomized and inserted into the kiln with a controllable amount of primary air. Recirculated flue gas in a countercurrent stream to the main air flow was introduced upwards from the bottom of the kiln. These experimental runs proved the soundness of the countercurrent air/gas stream principle. Later, three more kilns were converted to oil firing, based on results achieved from the experimental run with the first kiln over a period of one and a half years. Even after operating the four kilns with oil firing for several monthes, however, production still had to be regarded as in the experimental stage, mainly on account of problems arising from recirculation of hot flue gas.

4. The large scale oil firing experiments with the vertical kiln proved one important principle which later led to more improved kiln design - the increase of high temperature gas flow, involving high velocities and great pressure drops, improves the uniformity of heat

transfer in the sintering zone. This result shook the shaft kiln principle to its foundations, as earlier it was believed that the shaft kiln can only operate on high fixed carbon fuel, such as coke. However, every coke particle embedded in the material ignites and burns like a little sun, radiating heat to the material surrounding it and producing a gas flow of CO and CO_2 to move through the voids and pores. In such a process, radiant heat transfer from the glowing particle plays an important part and thus it is unavoidable that the raw material layers in the immediate vicinity of these particles are heated to a higher temperature than the layers farther from it. Furthermore, the fuel particle changes into ash which, chemically reacting with the closest raw material layer, forms eutectics at lower temperature than necessary for clinker sintering. Also high carbon fuels without an appreciable amount of volatiles, may produce local reducing atmospheres with disturbing influences on the crystallographic composition of clinker, as shown later.

5. Although recent attempts to reduce the size of the fuel particles by intergrinding with the raw material have brought great improvements, even better uniformity of temperature in the sintering zone can be achieved with a fuel, or blend of fuels, with a higher volatile content. With such fuel however, it is essential to produce absolutely uniform sized nodules and the sizing of the fuel particles must be as close as possible to the sizing of the raw meal. The good uniformity of the chemical composition of the raw meal and fuel-ash is of particular importance if the volatile content of the fuel rises higher.

6. If nodules of the right size are produced in the nodulizer, the temperature differential between the surface of the nodule and its core may reach 500 deg C. Thus each nodule is surrounded with a fast flowing stream of hot gas and air and the volatile matter in the fuel, reaching escape temperature while still in the nodule core, will ignite as soon as it joins the hot stream within the voids formed by the nodules.

7. With increased fineness of fuel there is also a marked increase of the chemical reaction between the fuel particles and the carbonates of the raw meal:- $CaCO_3 + C \rightarrow CaO + 2CO$. Thus, to a certain extent, oxidation of the fuel can start independently of air supply and this also contributes greatly to uniformity of sintering.

NODULIZER

8. The blend of pulverized raw meal and fuel is fed on the rotating nodulizer pan while a controlled amount of water is added through sprays. A rotating scraper keeps the pan clear to keep the active nodulizing surface constant. The nodules overflow through a stepped rim into a rotating spreader and then into the kiln.

9. The pan type nodulizer was introduced into the cement industry in Switzerland in 1947, and three years later in Australia. Since that time, the importance of this machine for a great variety of industries has been widely recognized all over the world. The superphosphate industry also realized the value of agglomerated dust-free fertilizer, and followed suit in all the major superphosphate works in Australia, by the introduction of nodulized superphosphate using the pan type nodulizer.

10. Experimental work is conducted in many fields of mining and metallurgy for the agglomeration of material, with a view to simplification of heating processes by the feasibility of economical

agglomerating by the new nodulizer.

11. The original nodulizer was not a success, in spite of several years of preliminary experimental work preceding the first application in 1947 in a Swiss plant. During the experimental period, the best result the nodulizer could achieve was a blend of nodules of varying size with moistened, deformed material.

12. The first plant that produced nodules of acceptable quality, in western Switzerland in 1947, was operating on dry, pre-mixed, raw meal and coke breeze to feed a kiln sintering portland cement clinker. However, even this nodulizer was far from perfect - material built up on its pan, and numerous other shortcomings impaired its performance. A considerable number of other experiments were carried out, concerning the most suitable angle and speed of the nodulizing pan and position of inlets for pulverized material and water.

13. A great variety of designs for automatic scrapers has been tried in Australia and overseas and here again, the most suitable type of scraper depends a great deal on the physical characteristics of the materials, since some pulverized materials produce extremely hard coatings on the pan; others behave differently. Application of scrapers has improved nodulizer performances to such an extent that with up-to-date machines, excellent nodules of uniform size can be obtained in nearly fully automated operation.

14. Over several years, large scale experiments were carried out with a rim extending the nodulizer pan. The most important data in this connection were received from Japan, covering the results of experimental operations with a nodulizer rim. It could be proved that application of the rim in feeding vertical kilns, sintering portland cement clinker, had eliminated completely any fine material from the nodules and had thus further improved uniformity of nodule size.

15. The nodulizing characteristics vary greatly with the different physical natures of the raw materials; their fineness is also of great importance. During the preliminary work preceding the introduction of the nodulizer into industrial practice, laboratory methods were devised to test the physical characteristics of the raw materials. The most suitable tests to check whether pulverized materials possess acceptable nodulizing characteristics, were established to be the following:-

(a) Formation of small pea-size balls from the pulverized material moistened and subsequently dried at 500C. Tests were made for mechanical abrasion and strength, either by vibrating on a suitable screen for different periods and measuring the wear loss, or by drop tests from different heights.

(b) Forming nodules in the laboratory with optimum amount of water, subjecting these nodules to consecutive drying and storing in air of defined moisture content and measuring moisture absorption and desorption. The figures so obtained proved to be an important guide for judging nodulizing characteristics.

16. Laboratory experiments proved that porosity of the nodules after drying has an important bearing on their physical properties during preheating at higher temperatures. Above a critical porosity, nodules show a tendency to crack up during the preheating process. It appeared that a certain minimum porosity is required to enable nodules to keep their shape during preheating and sintering. This minimum porosity varies, depending upon the type of material and its fineness.

17. Great progress has also been achieved during recent years in the mechanical perfection of the nodulizer. Completely enclosed gear boxes with silent gear transmissions, attached to the back of the pan, simplified designs, thus rendering the new nodulizers robust and non-sensitive, to assure long, reliable service.

18. FIGURE I shows cross section of the kiln and temperature chart. The rates of the feed of nodules into the kiln and the discharge of clinker through the rotating grate are the same so that the top material level in the kiln remains unchanged. The material in the kiln is moving down at a uniform rate of 4 ft 6 in per hr, corresponding to an output of clinker of 200 tons in 24 hours from one kiln. The air is moving upwards, so that the nodules moving downwards are getting hotter and hotter until the temperature is sufficient to ignite the coal particles incorporated in the nodules, producing the hot zone. Because of the excellent heat transfer rate, the temperature increase on a 3 ft kiln length is greater than 1360 deg C (from 100° C in the flue gases to 1460°C in the hot zone as indicated).

19. In the area above the hot zone, there may be an oxygen deficiency in the gases which may cause fuel particles in the nodules to reach temperatures at which their volatile matter may escape but, because of the shortage of oxygen, they may not fully ignite. Therefore secondary air must be provided in the area above the hot zone to supply oxygen for the combustion of the volatile matter that has reached escape (and ignition) temperature.

20. During 1957-58 large scale experimental runs were made with two kilns, using bell shaped cones from heat resistant castings to introduce air from the top of each kiln in a countercurrent stream to the main air flow coming up from the bottom; this is based on principles, referred to earlier, that were applied in the oil-fired vertical kiln. A great number of problems had to be solved in connection with this application. The accuracy required for proportioning and nodulizing was greater, asthe balance between air temperature and ignition temperature of volatile matter must be nearly perfect. Several months of experimenting were necessary before air introduction from the top operated successfully. There is however a 30% reduction in kiln output due to the smaller cross sectional area available in the sintering zone.

21. A much better method for the protection of volatiles in coal from premature escape without combustion is the coating of nodules, having the correctly proportioned coal content interground, by "white" meal, which has no coal content. By this method the output of the kiln is not reduced, as the cross sectional area of the hot zone remains intact, while due to more efficient combustion, fuel consumption is reduced by up to 20%. The combination of the coating process with the Spohn grate and the use of high volatile fuel opens up the way not only to a fully automated sintering process but also to a new method of cement clinker manufacture of unsurpassed efficiency and reliability.

22. Research work connected with this new vertical kiln required extensive studies and experimental work on porosity, gas flow in pores and voids, ignition of coal, ignition of the various groups of volatile matter, convective heat transfer from turbulent flowing gas to material surface and radiant heat transfer from flowing fuel particles to their immediate surroundings.

23. For the study of the various stages of preheating, a sampling

pipe was designed. This pipe was made by fitting two halves together, hinged on one side and with a sharp tip. It is pushed into the kiln from the top, then the two halves are opened, turned around and closed again so that the pipe withdraws from the kiln a representative cross-section of the various phases of preheating and sintering.

224. Bringing fuel particle sizing closer to raw material sizing presented many problems. The great advantages of finer fuel particles were recognized long ago as a possible contributory factor towards progressing with the vertical kiln; however, before the introduction of nodulizing and with the type of discharge equipment available 20 years ago, uniform operation of the kiln with finely ground fuel could not be achieved. But in 1955 Dr. E. Spohn introduced a new conical grate that brought the problem of using finely ground fuel much nearer to solution. Supported by excellent laboratory and large scale proving facilities, Dr. Spohn achieved uniform discharge of loose pea-sized clinker.

25. Finely ground fuel produces porous clinker in nodulized form, which cools almost in an air quenching fashion. The comparatively slow cooling of the old type vertical kiln cement clinker was regarded as a serious disadvantage, with full justification. It is well known that $3CaO.SiO_2$ crystals, formed by suitable heat treatment, can disintegrate into free CaO and $2CaO.SiO_2$ under various influences, notably slow cooling or cooling from an overheated state under chemically reducing conditions. The vertical kiln using finely ground fuel does not permit such disintegration because of porosity and consequent fast cooling of sintered nodules.

26. Table 1 shows the heat balance of the vertical kiln at a plant in Traralgon, Australia. The fuel consumption is very low in relation to conventional rotary kilns as operated in Australia; on the other hand the figures also show possibilities for important further improvement. Radiation loss through the kiln shell is still very great, thus pointing to the necessity of improved insulation, which modern vertical kilns can offer because their operating conditions have very little influence on the lining. It is not uncommon to have such kilns operating at maximum output on one lining for two years or more.

27. Important research work during the last four years has proved that heat loss from a vertical kiln is greatest in a material layer up to 4 in. from the kiln lining; it is also in this layer that sensitivity to disturbed temperature balance is greatest. Dr. H. Eigen refers to kilns that through complete insulation, consume less than 700 cal per kg of clinker. Very good results were also achieved with insulation of modern vertical kilns in Japan.

28. To achieve the accurate proportioning of fuel and raw material for the purpose of grinding these constituents together, a mill which retains the raw material and fuel particles in the grinding process only until the particle sizes reach the required level is most suitable. This is achieved by air carrying particles at this stage out of the mill through a rotating classifier into the discharge system.

29. A cement works in Isa, Japan, has successfully replaced air by kiln flue gas for the operation of mills of this type thus solving also an important problem of dust collection. This approach is quite possible if the alkali content of the raw materials is low. If, however the alkali content in the raw materials is high, the kiln

TABLE 1

HEAT BALANCE CALCULATED FOR 100 LB CLINKER

Heat input B.t.u. per 100 lb		Heat consumed B.t.u. per 100 lb
	For evaporation of water	36.300
	Decomposition of carbonates	91.629
	Loss of heat carried by CO_2 of raw meal	5.540
	Loss of sensible heat in exit gases	16.310
	Loss of sensible heat in clinker	5.400
	Loss of sensible heat in dust	.200
	Loss of some volatile matter and $CO+H_2$	8.331
	Radiation loss through kiln shell	29.931
18.000	Exothermic reaction	
.110	Organic matter in raw meal	
175.531	Heat carried into process by fuel	
193.641		193.641
	Theoretical heat requirement for 100 lb clinker:-	
	Decomposition of carbonates	91.629
	Less exothermic reaction	18.000
		73.629
	Efficiency	38%

gases will carry out most of the alkali. Any collected dust from these gases must therefore be disposed of to utilize the advantage of vertical kiln cement having very low alkali content. This advantage arises as a result of the high velocity of flue gases escaping from the hot zone into the atmosphere.

30. The above results of intensive research work in Australia, Europe and Japan have led to continuous improvements in the design of vertical kiln plants. The main problems are: accuracy of proportioning of fuel and raw material, controlled supply of air, fine grinding of raw meal and coal to prevent any marked differences in their sizing and uniform chemical composition.

31. The best method of controlling consistency of chemical composition is to work by the lime saturation method, and not titration of raw meal. According to this method raw meal sample and a measured amount of CaO are completely sintered under controlled conditions and the surplus CaO determined.

32. Many of the problems involved in perfecting modern vertical kiln

techniques are still very new and require further experimentation, as even the best ideas put into practice require some time before simple, ordinary routine operation may emerge.

33. Precision proportioning equipment for meal and coal (briquette dust is operating at present in the Traralgon plant previously referred to. After blending to the required chemical composition the meal is conveyed into a 20-ton capacity feeder hopper, the level of which is kept constant by a gauging device. The meal from this hopper flows through a variable speed cell feeder into the meal proportioning unit; this arrangement has eliminated the danger of floodings. The proportioning units for meal and fine coal were carefully selected and meet the demands for the required accuracy.

34. To operate the new vertical kiln with pulverized inter-mixed fuel must be an astonishing experience to all who had practice with the older type vertical kilns designed in the early 1950's. Manual work with iron bars is a matter of the past as are blow-outs or unevenness of operation. The kiln is completely silent; the "fire" i.e. progress of ignition of fuel particles, cannot be heard. All that has to be watched are the instruments and the nodule level in the kiln which must naturally be kept constant; i.e. feed and discharge rates must be in perfect equilibrium. Automation of this feature of kiln operation is also studied, and if constant level keeping is automated, no personnel would be required on the kiln platform.

35. The Gippsland Cement Co. operating with two vertical kilns is now producing at a rate of 400 tons per day. In March 1962 an all time record of 10,500 tons of clinker were produced. Peak production capacity from one kiln was 211 tons/24 hours. Total cost of plant including buildings, land etc. was £A1,200,000 or £A10 per ton annual production. At present 4 different brands of cement are manufactured: Normal Portland Cement "N", High Early Strength Cement "D", Sulphate Resistant Cement "R" and Masonry Cement "S" All brands are subjected to extensive testing not only in the Company's own laboratories but also in government testing institutions whose representatives can enter the plant unannounced for sampling at any time. Their tests of "N" Portland Cement prove not only absolute uniformity but also very sound quality figures, including conformity with the A.S.T.M. autoclave test requirements. The strength of "N" Cement is about 100% higher than required by Australian Standard Specifications while the results of "D" Cement are also consistently higher than required by A.S.T.M. high early strength standards. The decision to keep strengths very much above the required levels was motivated by the desire to overcome prejudice which is unavoidable if a new process, originating from the oldest process of cement manufacture, is trying a break through to prove its value by low cost, highly economical plant.

36. Establishment of cement manufacture on a relatively small scale which the new methods entail, must have a tremendous bearing on the improvement of standard of living in under developed areas.

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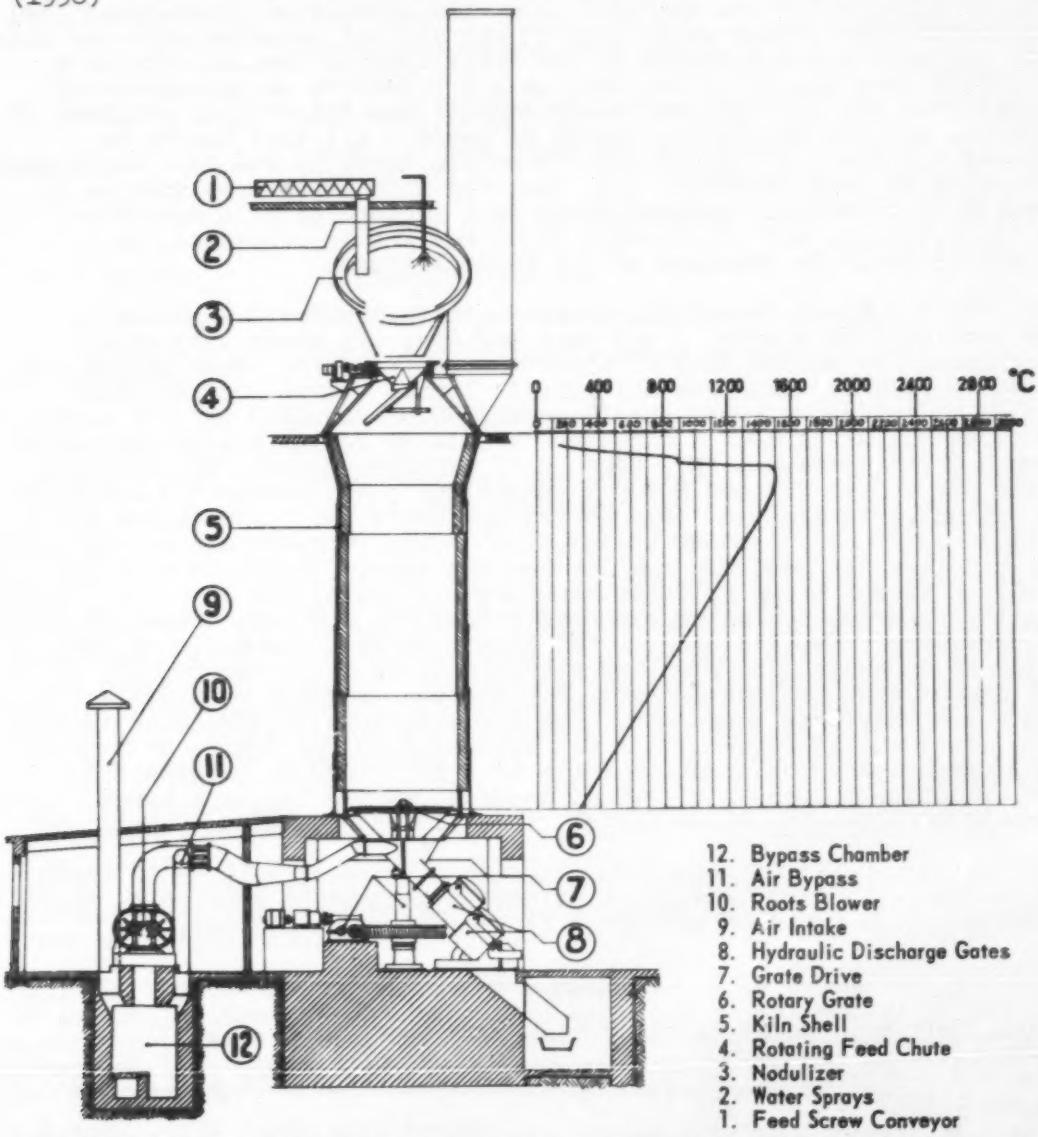

FIG. I. - Cross section of a vertical cement kiln with temperature chart in deg C. Major items of equipment are shown 1. - 12.

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